

Microgravity Emissions Laboratory Testing of the Light Microscopy Module Control Box Fan

Anne M. McNelis
Glenn Research Center, Cleveland, Ohio

Sergey Samorezov
ZIN Technologies, Inc., Cleveland, Ohio

Anthony H. Haecker
Northrop Grumman, Brook Park, Ohio

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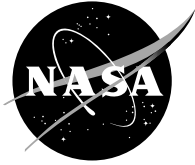
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Anne M. McNelis
National Aeronautics and Space Administration
Glenn Research Center
Cleveland, Ohio 44135
Anne.M.McNelis@nasa.gov

Sergey Samorezov
ZIN Technologies, Inc.
Cleveland, Ohio 44142
Sergey.Samorezov@grc.nasa.gov

Anthony H. Haecker
Northrop Grumman Corporation
Brook Park, Ohio 44142
thaecker@mrdoc.cc

Summary

The Microgravity Emissions Laboratory (MEL) was developed at the NASA Glenn Research Center for the characterization, simulation, and verification of the International Space Station (ISS) microgravity environment. This Glenn lab was developed in support of the Fluids and Combustion Facility (FCF).

The MEL is a six-degrees-of-freedom inertial measurement system that can characterize the inertial response forces (emissions) of components, subrack payloads, or rack-level payloads down to 10^{-7} g. The inertial force output data generated from the steady-state or transient operations of the test article are used with finite element analysis, statistical energy analysis, and other analysis tools to predict the on-orbit environment at specific science or rack interface locations. Customers of the MEL have used benefits in isolation performance testing in defining available attenuation during the engineering hardware design phase of their experiment's development.

The Light Microscopy Module (LMM) Control Box (LCB) fan was tested in the MEL in June and July of 2002. The LMM is planned as a remotely controllable on-orbit microscope subrack facility that will be accommodated in an FCF Fluids Integrated Rack on the ISS. The disturbances measured in the MEL test resulted from operation of the air-circulation fan within the LCB. The objectives of the testing were (1) to identify an isolator to be added to the LCB fan assembly to reduce fan-speed harmonics and (2) to identify the fan-disturbance forcing functions for use in rack-response analysis of the LMM and Fluids Integrated Rack facility. This report describes the MEL, the testing process, and the results from ground-based MEL LCB fan testing.

Introduction

The accelerations generated by various operating components of the International Space Station (ISS), if too large, could hinder the science performed on the station by disturbing the microgravity environment. A special testing laboratory, the Microgravity Emissions Laboratory (MEL), was developed at the NASA Glenn Research Center to help characterize on-orbit microgravity capabilities through ground-based tests (ref. 1; Kienholz, David A.: Operating and Maintenance Manual for Pneumatic Suspension Systems. Report No. 02-05-04, CSA Engineering, Inc., 2002, internal report; Houston, M.C.:

Test Procedure for the Setup of the CSA Engineering, Inc., Pneumatic Suspension System for the Microgravity Emissions Laboratory. Report: MEL–TRPO–004–CSA, 2000, internal report; and Houston, M.C.: Test Procedure for the Experimental Determination of Microgravity Emissions Laboratory Test Assembly Mass Moments of Inertia Using Bifilar Pendulum Method. Report: MEL–TPRO–001–Rev1, 2002, internal report).

The laboratory uses a pendulum-based, low-frequency acceleration measurement system with precision isolation systems that allow for very low spring rates and provide protection from environmental dynamic influences. This Glenn lab can characterize inertial forces and moments for ISS microgravity disturbers including operating fans and pumps. Over 30 microgravity ground-based tests have been performed at the MEL for current and future ISS payloads.

Some MEL customers need to determine their flight article's assembly-level generation of inertial forces for comparison with ISS vibration requirements. Other MEL customers, who are at a development level in their design process, need testing to aid in their selection of engineering-level hardware during the design and buildup of their test experiment. Their goal is to identify the natural vibration frequencies of the operating test components and to quantify the reduction in inertial forces and moments that could be obtained with specialized isolation treatments. The design goal is to eliminate any component-level responses in the natural frequency regime expected for the ISS rack. Having a response at the rack-level natural frequency could produce a microgravity vibration environment nonconductive to conducting the intended science experiments of the rack. In addition, the unwelcome rack response paired at the same frequency of the component excitation frequencies could disturb nearby science-rack experiments.

The levels of vibration measured from these ISS components are typically 10^{-2} to 10^{-6} times the normal 1g environment of the Earth's gravitational acceleration level. The inertial acceleration and mass properties measured for every MEL test are defined at the center of gravity of the test unit and are obtained by postprocessing the accelerations measured with the mass and mass moment of inertia of the test setup (McNelis, A.M.; and Samorezov, S.: Microgravity Emissions Lab Test Report of the LMM Control Box Fan. Microgravity Emissions Laboratory Test Reports: MEL–TR–02–05, MEL–TR–02–06, 2002, internal report). Payload developers can apply the six-degrees-of-freedom forces and moments to finite element analysis and statistical energy analysis models to determine the science-rack-level response due to operation of their component hardware.

The purpose of this report is to highlight the Light Microscopy Module (LMM) Control Box (LCB) fan MEL testing and compare the inertial forcing functions obtained for operation at various isolation treatments and fan speeds. The customer's goal during this MEL test was to reduce the fan-related response amplitudes at the fundamental and harmonic tonal frequencies and to reduce the random vibration between 40 and 60 Hz and around 100 Hz. The accuracy and focusing capability for the complete LMM optics assembly would be compromised without careful consideration of the self-disturbance vibrations generated by the LCB fan at frequencies of 40 to 60 Hz and 100 Hz. Various isolation treatments were applied, and inertial forces and moments characterized using the MEL were calculated to measure the effect of the isolation treatments applied.

Microgravity Emissions Laboratory

Located in the Structural Dynamics Laboratory at Glenn, the MEL is a unique facility in that it can measure ISS-component operational acceleration emissions as low as $0.10 \mu\text{g}$ (1.0^{-7}g). The MEL accelerometer platform, which the underside of the unit being tested is mounted to, is shown in figure 1. The laboratory is a pendulum-based, low-frequency (down to 0.15 to 0.20 Hz) isolator. The pneumatic isolation mechanisms—which are manufactured by CSA Engineering, Inc., Mountain View, California—suspend the measurement apparatus with the rigidly attached test unit by a long suspension cable. The pneumatic isolation mechanisms reduce the system's vertical frequencies by bearing the weight of the payload through a semipassive frictionless air spring (Kienholz, David A.: Operating and Maintenance Manual for Pneumatic Suspension Systems. Report No. 02–05–04, CSA

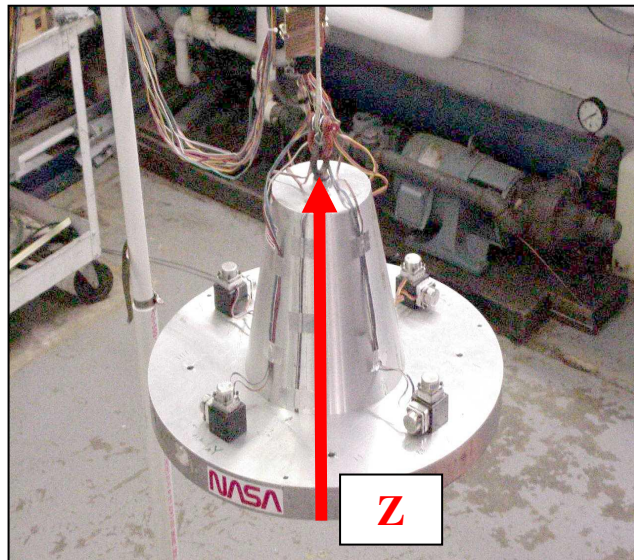


Figure 1.—Microgravity Emissions Laboratory (MEL) accelerometer platform with Z-axis indicated.

Engineering, Inc., 2002, internal report). Vertical mounting space for rack-size testing is 3 by 3.5 by 7 ft. The typical test assembly size is 2 by 2 by 2 ft.

The MEL apparatus is equipped with five pairs of accelerometers (QA-700, Honeywell, Redmond, WA). There are three measurements in the X, three in the Y, and four in the Z direction. One pair of X, Y accelerometers is close to the top center of the MEL platform, and the rest are near the bottom of the platform. The test apparatus is attached to the isolation system by a 33-ft suspension cable.

The testing unit is attached to the underside of the MEL platform with a rigid mounting interface, which constrains the isolated system to rigid-body motion. Test unit operating conditions are measured as the assembly is suspended from isolation mechanisms by the suspension cable (Houston, M.C.: Test Procedure for the Experimental Determination of Microgravity Emissions Laboratory Test Assembly Mass Moments of Inertia Using Bifilar Pendulum Method. Report: MEL-TPRO-001-Rev1, 2002, internal report; and McNelis, A.M.; and Samorezov, S.: Microgravity Emissions Lab Test Report of the LMM Control Box Fan. Microgravity Emissions Laboratory Test Reports: MEL-TR-02-05, MEL-TR-02-06, 2002, internal report). The mechanical and pneumatic suspension mechanisms are rated for 600, 750, or 1200 lb and can be used in parallel to accommodate larger weight ISS-rack applications.

The MEL test approach is to obtain acceleration emissions of operating test components that are rigidly attached to the MEL accelerometer platform. The forces and moments are a product of the full diagonal mass matrix, including the test setup center of gravity, the mass moment of inertia, the weight, and the resolved rigid-body acceleration vector derived from the five pairs of MEL QA-700 accelerometer measurements. The measured motion of the rigid body is characterized through the MEL test, and the accelerometer data are postprocessed to calculate the rigid-body component forces and moments at the center of gravity or interface science region of interest. Mass moments of inertia in each axis of the combined MEL apparatus and the test unit are experimentally determined using the bifilar torsion pendulum method (McNelis, A.M.: Procedure for Calculation of Forces and Moments from MEL Accelerometer Platform Data. Report: MEL-TPRO-005, Rev 1, 2002, internal report).

Time-history data are acquired with the five pairs of MEL accelerometers during various steady-state and transient operation conditions of the test unit and for ambient or noise-floor readings. Each testing condition is acquired with enough resolution to attain one-third-octave frequency content up to 315 Hz. Many output data formats are processed and stored for each test, including time-history domain force and

moment data, as well as force and moment power spectral density, linear spectrum in narrowband, or one-third-octave band representations.

Applying a time-domain methodology to the measured accelerations generates MEL force and moment data. The Glenn time-domain methodology program is run with PC-based test software (MTS—IDEAS Test Software, Eden Prairie, MN). The time-domain methodology determines the rigid-body center-of-gravity vector from the basic geometry of the MEL/experiment assembly test setup.

Inherent Natural Frequencies

The fundamental frequency of the current MEL platform is 380 Hz. All fixtures developed to attach test articles to the MEL are evaluated for assurance that they will not have natural frequencies within the 0- to 315-Hz regime of the ISS requirements.

The lateral frequencies are established with the pendulum, which has natural frequencies obtained from the following equation:

$$f \text{ (Hz)} = \frac{1}{2\pi} \sqrt{\frac{g}{L}}$$

The first lateral pendulum natural frequency is 0.156 Hz. This is characterized by the suspension cable length of 33 ft (L). The second pendulum natural frequency is characterized by the length between the platform attachment point and the center of gravity of the assembly being tested; it typically falls near 0.3 Hz. The vertical mode is lowered by the pneumatic isolation system mechanisms that reduce the vertical frequencies to 0.1 to 0.2 Hz.

Light Microscopy Module Facility

The LMM is a component of the Fluids Integrated Rack (FIR) of the Fluids and Combustion Facility (FCF) (ref. 2). The LMM concept is a modified commercial research imaging light microscope with powerful laser-diagnostic hardware and interfaces, creating a unique, state-of-the-art microscopic research facility. The microscope will house several different lens objectives corresponding to various magnifications. The engineering, design, and development of the LMM are being performed under NASA contract with the Northrop Grumman Corporation.

The LCB houses the LCB air-circulation fan, the LCB power supply, the PC/104 computer system, and the motion control system. The LCB power supply converts input voltage to that required to operate the LMM. The PC/104 computer system contains the central processing unit and other circuit boards that provide the signals for motion control, data acquisition, and communications. The motion control system consists of driver circuit boards that use the motion control signals from the computer system to drive the various motors and actuators on the LMM.

This testing was done to measure the microgravity disturbances generated by a small 2.54-lb air-circulation fan during startup, shutdown, and steady-state operations. A matrix of 12, 9, and 7-V power supply voltages and corresponding fan speeds were tested. The goal was to reduce disturbances caused by the airflow and the harmonics of the fan-turning speed. Several isolators (Lord Corporation MPD, Erie, PA) with varying stiffnesses were tested and used to integrate the best performing (with respect to the LMM customer's hardware performance needs) isolation treatment within the fan assembly. A hard-mounted test was also conducted without any isolation treatment to demonstrate the comparative benefit of isolating the fan setup.

Test Methodology and Results

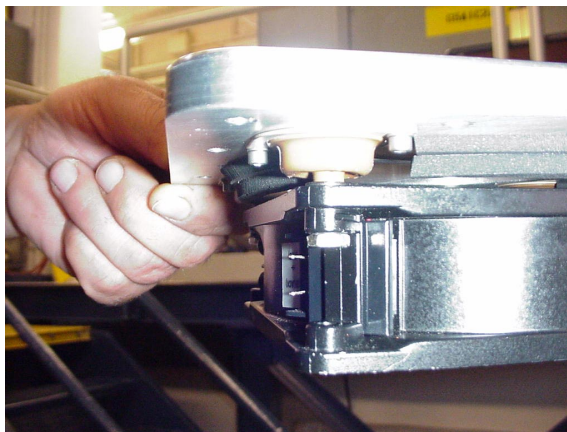


Figure 2.—3-lb/in. isolators installed.

The 2.54-lb fan was mounted to the MEL accelerometer platform using a fan-adapter standoff fixture plate, as shown in figure 2. The first candidate isolator provided by the customer had a stiffness of 8 lb/in. Four 8-lb/in. isolators were inserted between the fixture adapter plate and the fan. The MEL platform was suspended with the laboratory's pneumatic system to isolate it from any surrounding dynamic influences.

The LCB fan operational data were acquired using the 10 MEL accelerometer readings for 360 sec of steady-state operation of the fan at fan speeds of 7 V (1636 rpm), 9 V (2264 rpm), and 12 V (3056 rpm). These speeds represented the matrix of all possible on-orbit fan speeds that were being considered.

Figure 3 is a representation of the inertial forces in the Z-axis of the MEL assembly generated from the 2264-rpm-fan-speed steady-state operation. The Z-axis of the MEL assembly is parallel to the isolator axis of insertion. The fan-speed operational fundamental and harmonic frequencies are noted at 37, 75, 113, and 152 Hz for the five-blade fan. Electrical noise found at 60 Hz and its harmonics (120 and 180 Hz) was present in the data and was discounted from all of the following comparisons for fan operational data.

The inertial force at the fan-speed tonal frequency was 7.57×10^{-4} lbf, which is greater than that for the hard-mounted fan. Wideband random vibration within the 40- to 60-Hz frequency range suggested that a softer isolator should be tested as the next approach. Similar results were obtained for the other fan speeds tested and for the X- and Y-axes of the MEL assembly.

Next, the second candidate isolators, with a stiffness of 1 lb/in., were inserted into the fixture/fan MEL test setup. The assembly was again suspended, and operational data for 7, 9, and 12 V were obtained. The results from this experiment showed that an isolator with a stiffness greater than 1 lb/in. but less than 8 lb/in. should be tested for comparison. Figure 4 shows the translation force (Z-axis) data for the 1636-rpm fan speed (7 V), with a comparison made between hard mounting and 8- and 1-lb/in. isolation. At this fan speed, the hard-mounted condition shows the least random vibration in the 40- to 60-Hz frequency range. The lack of isolation at 95 Hz using the 1-lb/in. stiffness isolators is apparent, as shown in figure 4.

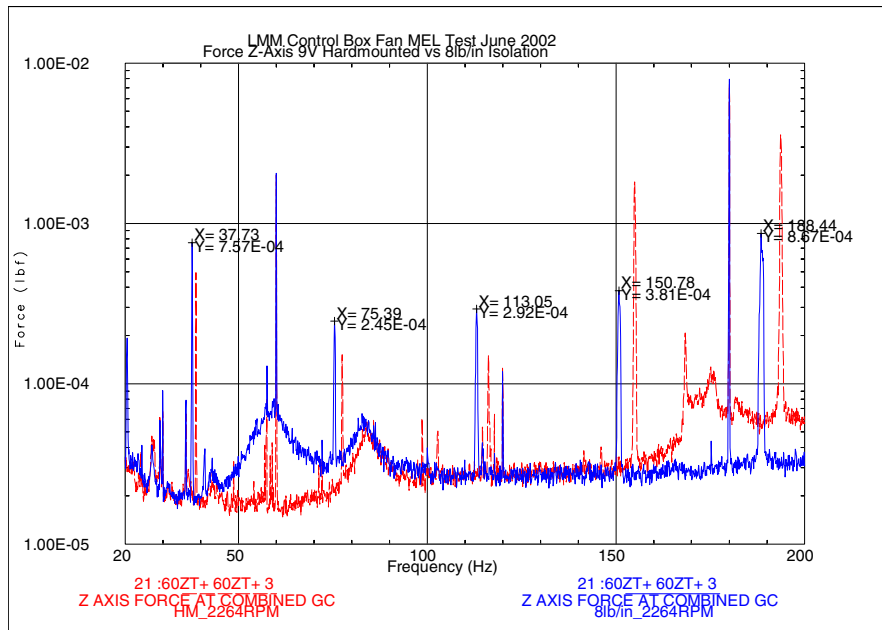


Figure 3.—Microgravity Emissions Laboratory (MEL) inertial force Z-axis comparison of hard-mounted Light Microscopy Module Control Box (LCB) fan and fan with 8-lb/in. isolation at the 2264-rpm speed.

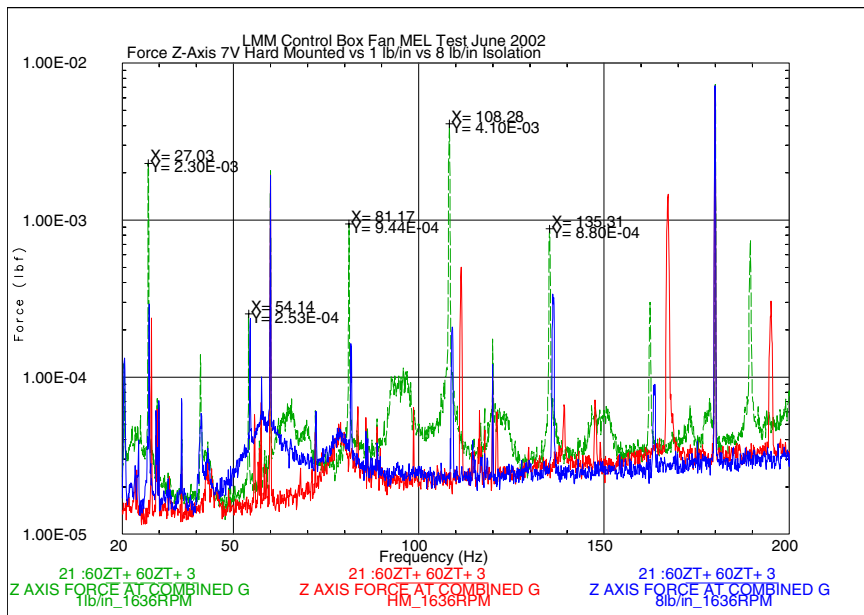


Figure 4.—Microgravity Emissions Laboratory (MEL) inertial force comparison of hard-mounted Light Microscopy Module Control Box (LCB) fan and fan with 1- and 8-lb/in. isolation.

Finally, the third through fifth isolator candidates, with stiffnesses of 3, 5, and 20 lb/in., respectively, were obtained from Lord Corporation. They were inserted into the fan/MEL assembly, and the fan was again run at speeds of 7, 9, and 12 V. Figure 5 shows the translation force in the Z-axis of the MEL assembly for the 3-, 5-, and 20-lb/in. isolators. The best isolators for reducing the random vibration between 40 and 60 Hz were the 3- and 5-lb/in. candidates. It appears that the 3-lb/in. isolator was better at reducing the amplitude of the fan-speed harmonic response as shown for the 2264-rpm (38-Hz) test. At 38 Hz, the 3-lb/in. isolated fan generates 1.35×10^{-4} lbf, as shown in figure 5. The 5-lb/in. isolator exhibited the highest peaks at the fan-speed harmonic frequencies. Similar results were found for the other fan speeds and for the X- and Y-axes of the MEL assembly setup. The 3-lb/in. stiffness isolator provides sufficient isolation at 100 Hz in comparison to the 5- and 20-lb/in. isolators.

Figure 6 compares the most ideal isolator and the hard-mounted condition for the 2264-rpm (9-V) fan speed. The wideband random vibration noise is pushed out past the 40- to 60-Hz frequency range, and the harmonics of the fan-speed rotational frequency are greatly reduced.

A goal was set to test a selection of isolation treatments and obtain a set of inertial forces to measure the response of the fan with and without isolation treatment. The customer was able to continue the engineering hardware design with several isolation treatment options and to characterize the fan response using these treatments. The customer was able to use the MEL data (obtained for the forces and moments generated by the fan at several fan speeds) in analysis programs to quantify the preliminary FCF FIR-level response for comparison to ISS requirements (McNelis, A.M.; and Samorezov, S.: Microgravity Emissions Lab Test Report of the LMM Control Box Fan. Microgravity Emissions Laboratory Test Reports: MEL-TR-02-05, MEL-TR-02-06, 2002, internal report).

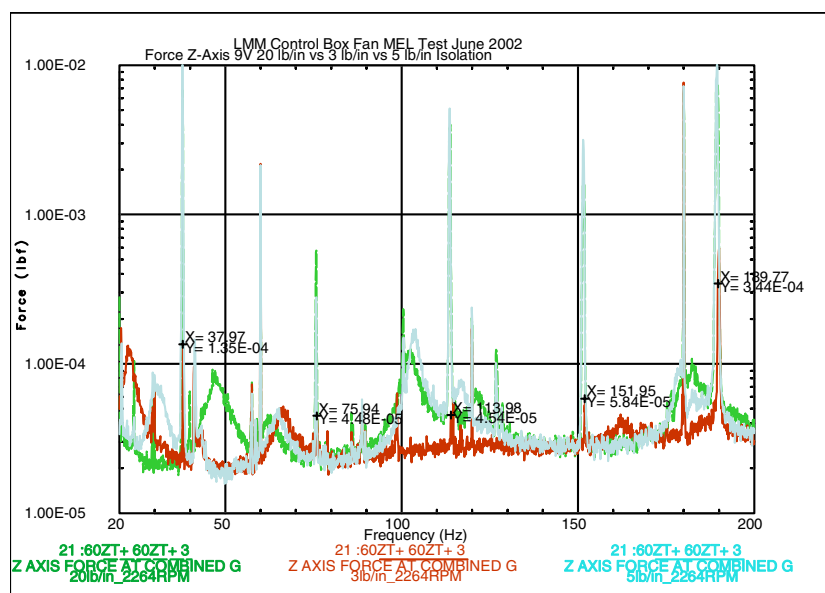


Figure 5.—Microgravity Emissions Laboratory (MEL) inertial force Z-axis comparison of Light Microscopy Module Control Box (LCB) fan with 20-, 3-, and 5-lb/in. isolation.

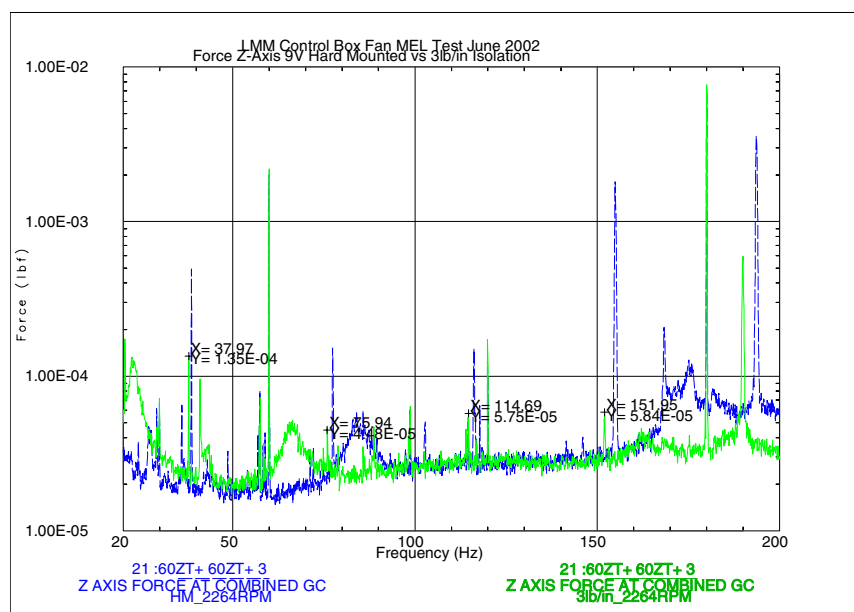


Figure 6.—Microgravity Emissions Laboratory (MEL) inertial force Z-axis comparison of hard-mounted Light Microscopy Module Control Box (LCB) fan and fan with 3-lb/in. isolation at the 2264-rpm speed.

Conclusions

The NASA Glenn Research Center's Microgravity Emissions Laboratory (MEL) utilizes a low-frequency acceleration measurement system to characterize rigid-body inertial forces generated by various operating components of the International Space Station (ISS). The MEL data can be obtained at the component level of the test assembly as well as at the full buildup of the experiment for comparison with ISS vibration requirements, which are typically 10^{-2} to 10^{-6} times Earth's 1g gravitational acceleration level. The MEL has the measurement accuracy, isolation, and precision to obtain measurements as low as $0.10 \mu\text{g}$.

The Light Microscopy Module (LMM) is a component of the Fluids Integrated Rack (FIR) of the Fluids and Combustion Facility (FCF) rack. The LMM concept is a one-of-a-kind microscopic research facility with powerful laser-diagnostic hardware. The LMM Control Box (LCB) fan was tested in the MEL in June of 2002. This provided the LMM customer with valuable test information about a set of treatments that were being considered to isolate the fan. MEL inertial force and moment data were characterized for the isolated fan so that it could be used in analysis programs to predict FCF FIR compliance with ISS requirements.

Not only can the MEL characterize the low microgravity environment for complex assemblies, but it can measure the relative effectiveness of isolation treatments for the design and buildup of the vibratory components of the ISS.

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